Closing the Circle on the Splitting of the Atom

II. BUILDING NUCLEAR WARHEADS: THE PROCESS

Haystack Mountain, near Grants, New Mexico, is the richest uranium-mining district in the United States. After uranium deposits were discovered here in 1950, many large underground and open-pit mines were opened in the area, and some operations continued until 1990. *Grants, New Mexico. August 19, 1982.*

The production of nuclear weapons requires special technologies that were invented for the Manhattan Project. It also requires special materials: highly enriched uranium and plutonium. Both are made, by different processes, from naturally occurring uranium ore. Mining uranium ore is thus the first link in a chain of complex processes that eventually produce a nuclear weapon.

Although plutonium and uranium are both essential parts of modern nuclear weapons, it is possible to make nuclear weapons by using one or the other material alone. In fact, the first generation of atomic weapons did so. Early nuclear weapons were of two types: (1) gun-type bombs using two masses of highly enriched uranium, forced together very quickly to assemble a "critical mass" that would sustain a nuclear chain reaction and subsequent explosion; and (2) implosion bombs using high explosives to squeeze together a sphere of plutonium very quickly and symmetrically into a critical mass to attain a nuclear explosion. The "Little Boy" bomb dropped on Hiroshima was a uranium gun-type weapon, while the bomb dropped on Nagasaki was a plutonium implosion bomb. As designs for nuclear weapons advanced, a new generation of bombs – thermonuclear weapons – evolved. Most modern nuclear weapons use both plutonium and uranium.

Tritium is another essential material in most nuclear weapons. It is a radioactive gas that is produced by bombarding lithium with neutrons in a reactor. It is used to boost the explosive power of many modern weapons.

A model of a uranium atom is displayed at the American Museum of Science and Energy in Oak Ridge. Uranium is the basic element from which nuclear explosives are made. *Oak Ridge, Tennessee. June 11, 1982.*

Special Nuclear Materials

In nature, more than 99 percent of the atoms in uranium have an atomic weight of 238. From this, the remaining 1 percent, a particular atomic form, or isotope, with a weight of 235 must be physically separated in sufficient quantities to sustain a nuclear chain reaction–either for generating electrical power or, at much higher concentrations, for explosives.

Separating sufficient quantities of uranium 235 requires enormous amounts of energy and the meticulous operation of large, complex facilities. During the Manhattan Project, two separation methods were pursued simultaneously: electromagnetic separation in the "Calutron" (California University Cyclotron) and gaseous diffusion. Facilities for both methods were built at the Oak Ridge Reservation in Tennessee.

Since then, however, gaseous diffusion has generally been used in the United States to enrich uranium. The process involves a series of vast structures designed to drive gaseous uranium at controlled temperatures and pressures through miles of filters that gradually collect uranium 235 atoms in increasing concentrations–a process called "uranium enrichment." Two additional diffusion plants were built in Ohio and Kentucky in the 1950s.

Highly enriched uranium (more than 20 percent uranium 235, and typically more than 90 percent) is used in nuclear weapons. Low-enriched uranium, consisting of less than 20 percent uranium 235, is nearly impossible to make bombs with, but is used as fuel for nuclear reactors. The uranium 238 that is removed in the enrichment process is called "depleted uranium." It is used in some nuclear weapon parts as radiation shielding, in tank armor, and in armor-piercing bullets. It is also used to make plutonium.

Scientists knew they could avoid the trouble of enriching uranium if they could produce another nuclear material that could be chemically separated from impurities for use in bombs. That material was plutonium 239–an element that is created in nuclear reactors. In the nuclear fuel for a production reactor, uranium 235 is split into a host of radioactive byproducts; in the process, it releases neutrons. The neutrons bombard the uranium 238 in the fuel and transform it into the heavier element, plutonium 239.

Plutonium, like uranium, is a mix of several isotopes. Material rich in the isotope plutonium 239 is referred to as "weapons-grade plutonium."

After plutonium 239 has been created in the reactor, workers must separate it from the uranium and the radioactive byproducts (fission products) in a reprocessing plant. This plant dissolves irradiated uranium in acid and then extracts the uranium and plutonium, leaving behind a highly radioactive liquid referred to as high-level waste.

Because radiation levels inside a reprocessing plant are very high, the plant must be heavily shielded and operated by remote control to protect workers and the environment.

The Trinity nuclear test took place on this spot in the Alamogordo desert of New Mexico. In the background, a stone monument identifies the epicenter of the world's first nuclear explosion. In the foreground is a duplicate outer casing of the Nagasaki bomb. Both the Trinity and the Nagasaki bombs used plutonium cores. *White Sands Missile Range, Alamogordo desert, New Mexico. July 16, 1985.*

Uranium Mining

Most of the uranium for the Manhattan Project came from rich deposits in Africa and Canada, but more than 400 mines eventually opened in the United States, primarily in Arizona, Colorado, New Mexico, Utah, and Wyoming. After World War II, uranium mining expanded dramatically, from 38,000 tons of ore in 1948 to 5.2 million tons in 1958 – nearly all of it for nuclear weapons production. The United States mined about 60 million tons of ore to produce this uranium. Many tons of natural uranium were needed to produce the several kilograms of enriched uranium used in the Hiroshima bomb. For each kilogram of plutonium made for the U.S. arsenal, miners took roughly 1,000 tons of uranium ore from the ground.

Uranium Milling

A ton of uranium ore yields only a few pounds of uranium metal. The result is a dry purified concentrate called "yellowcake." The milling produces large volumes of a sandlike byproduct called "mill tailings." These tailings contain both toxic heavy metals and radioactive radium and thorium. Uranium – mill tailings account for a small fraction of the radioactivity in the byproducts of weapons production, but they constitute 96 percent of the total volume of radioactive byproducts for which Environmental Management is responsible. Because uranium mills typically piled tailings without covers or containment, some material was spread by wind and water. The primary hazard of these tailings is the emission of the radioactive gas radon. The Congress passed a law in 1978 to ensure that these tailings would be adequately stabilized.

Most of the uranium for the Manhattan Project came from from Africa and Canada. Later more than 400 mines opened in the United States.

Converter vessels in a gaseous-diffusion plant contain porous barriers that enrich uranium in gaseous form by separating out the atoms of uranium 235 from more-abundant uranium 238. Each of these vessels is a stage in the enrichment process, and there are a total of 5,122 stages at this plant. The more stages uranium hexafluoride gas passes through, the higher its enrichment becomes. *Unit 7, Cell 2, K-33 Demonstration Cell, K-25 Site, Oak Ridge, Tennessee. June 21, 1993.*

Uranium mills shipped the yellowcake to plants that refined the concentrate into forms suitable for several different roles in weapons production. Metallic uranium was used as fuel in the plutonium-production reactors at Hanford and at the Savannah River Plant. The Fernald Plant in Ohio was the principal site where many thousands of tons of uranium were refined, and sent to the enrichment plants at Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio, to be used in processes that separated and concentrated the uranium 235.

Uranium Enrichment

To make highly enriched uranium, the enrichment plants used an elaborate process to separate most of the rare uranium 235 from the more abundant uranium 238 isotope. The U.S. Government used most of the highly enriched uranium produced between 1943 and 1964 to make nuclear weapons.

The government made additional highly enriched uranium, with an enrichment of 20 to 90 percent, until 1992. The highly enriched uranium not used in weapons has been used primarily as a fuel for plutonium-production reactors or naval propulsion reactors. Smaller quantities have been used in research reactors. The government plants made a total of 994 tons of highly enriched uranium.

The vast majority of the material fed into the enrichment plants came out as depleted uranium, also called enrichment “tails.” Many thousands of tons of depleted uranium are still stored in cylinders in Ohio, Tennessee, and Kentucky. Moreover, operations at enrichment plants over the years caused extensive environmental contamination with solvents, polychlorinated biphenyls (PCBs), heavy metals, and other toxic substances.

Uranium Metallurgy

Uranium is converted into metal before it is used in nuclear weapons production. Workers at the Fernald uranium foundry in Ohio converted hundreds of tons of uranium hexafluoride gas (the "tails" from the enrichment process) into uranium"green-salt" crystals. These crystals were blended with magnesium granules and cooked in a furnace. The mixture ignites, converting the green-salt crystals into uranium metal. Some of this metal was made into reactor fuel or target elements for plutonium production reactors at Hanford and Savannah River. The Rocky Flats Plant in Colorado and the Y-12 Plant in Oak Ridge, Tennessee, formed depleted and enriched uranium metal into components for nuclear weapons. Releases of uranium dust and leaking landfills of chemicals were the primary environmental impacts of these operations.

Many thousands of tons of depleted uranium are stored in cylinders in Ohio, Tennessee, and Kentucky.

Uranium hexafluoride cylinders are stored near the K-25 Gaseous Diffusion Plant. Each cylinder contains 10 to 14 tons of depleted uranium hexafluoride. The K-25 plant stores about 5,000 of these cylinders, some of them 40 years old. Here, a worker is using ultrasound to evaluate the effects of external corrosion on a steel cylinder. Cylinders closest to the ground can experience accelerated corrosion. *K-1066K Cylinder Storage Yard, K-25 Site, Oak Ridge, Tennessee. January 9, 1994.*

Final inspection of uranium "billets." These billets of depleted uranium metal were produced at the Fernald Plant to be used as the cores of Mark 31 targets. Jack Schick, a metals worker, conducts a final inspection of a new batch before shipping them to the Savannah River Site, where they would be clad in aluminum, bombarded with neutrons, and partly transformed into plutonium. *Plant 6, Fernald Feed Materials Production Center, Fernald, Ohio. December 17, 1985.*

To produce plutonium, workers at the Hanford and Savannah River Sites processed hundreds of thousands of tons of uranium.

Plutonium Production

Between 1944 and 1988, the United States built and operated 14 plutonium-production reactors at the Hanford and Savannah River Sites, producing a total of about 100 metric tons of plutonium.

After the uranium from Fernald was coated with aluminum or zirconium metal, it was assembled into reactor fuel and targets. The Hanford Site's nine reactors all consist of large cubes of graphite blocks with horizontal channels cut in them for the uranium fuel and cooling water. The fuel slugs were inserted into the front face of the reactor where they underwent neutron bombardment. Then they were gradually pushed through the channels until they fell out the other side. The Savannah River Site's five reactors are different. They each consist of a large tank of "heavy water" in which highly enriched fuel and separate depleted-uranium targets were submerged. Because only a small fraction of the uranium in fuel and targets was converted to plutonium during each cycle through a reactor, workers at Hanford and Savannah River processed hundreds of thousands of tons of uranium. The production reactors at Savannah River also made tritium.

Jack Weaver: A Worker at Rocky Flats

Jack Weaver is one of the few old-timers working at the Rocky Flats Environmental Technology Site, the former nuclear weapons plant in Colorado. Only about two dozen of the 7,000 employees now at Rocky Flats have been there longer than Weaver. The accelerating exodus of experienced workers from Rocky Flats has led Weaver to take on the role of teacher and site historian.

"I'm concerned about the number of people we've lost over the past few years and the knowledge they've taken with them," says Weaver. As the manager of operations of one of the oldest plutonium processing buildings at the site, Weaver has seen it all. He worked there when Rocky Flats received plutonium from other sites to purify and fashion it into triggers for nuclear war. He has seen the consequences of mishandling plutonium. He saw plutonium fires. He knows safety rules are not merely paper exercises.

Weaver began his career at Rocky Flats in 1961 at the age of 20. "They told me it was a good place to work, that the pay and benefits were good," he says. At the time he started, there were 1,430 workers at the site. Within a year, increased production requirements raised that number to about 2,500. Weaver became a chemical operator and then worked his way up to operations manager.

"We went from a couple shifts, five days a week, to around the clock, seven days a week," Weaver says. "The Cold War was on and we all felt we had an important job to do for the country. We were all proud of what we were doing."

As proud as they were, however, the workers couldn't do much boasting. "Nobody talked about what we were doing in those days," Weaver says. "We didn't even talk about it amongst ourselves, let alone with our families and friends offsite. On the floor even, we referred to "Y" or "Z" or "U" and not to beryllium or plutonium or enriched uranium."

"So a lot has changed from those days, now that the Cold War and production mission are over and with the new openness policies," Weaver says. "The biggest change at the site came with the curtailed operations in 1989 after we were shut down."

With the Department's new openness, Weaver is able to dedicate himself to educating people about the site. "I now see myself as a teacher and guide, letting people know what we did here during the days of the Cold War, so that maybe they will have an understanding of what went on," Weaver says. "I've seen a lot in 33 years, and it should be of good use to someone."

The head of the K Reactor is seen here through a 4-foot-thick window of lead-glass shielding. Uranium-metal targets were placed inside the reactor and bombarded with neutrons to convert the uranium to plutonium. This reactor also bombarded lithium targets to make tritium, a gas used to boost the explosive power of nuclear weapons. *Savannah River Site, South Carolina. January 7, 1994.*

This tritium facility extracted tritium gas from lithium reactor targets. *Savannah River Site, South Carolina. January 7, 1994.*

The B Plant canyon was the world's second large-scale reprocessing facility. It dissolved irradiated fuel rods in acid to recover plutonium. *Hanford Site, Washington. November 15, 1984.*

Extraction of Special Nuclear Materials

The irradiated fuel and targets discharged from production reactors contained hundreds of different radioactive isotopes, collectively called "fission products." These had to be separated from the uranium and plutonium. Scientists developed chemical processes to accomplish this separation. Because exposure to even small amounts of these fission products would be lethal in a short time, workers could handle them only by remote control behind lead-glass shielding and thick concrete walls. In the United States, eight of these chemical separation plants, called "canyons," were operated for recovering plutonium and uranium until the late 1980s. For example, the PUREX facility at the Hanford Site in Washington operated from 1956 to 1972 and resumed operation from 1983 through December 1988. Plants were also operated in South Carolina and Idaho.

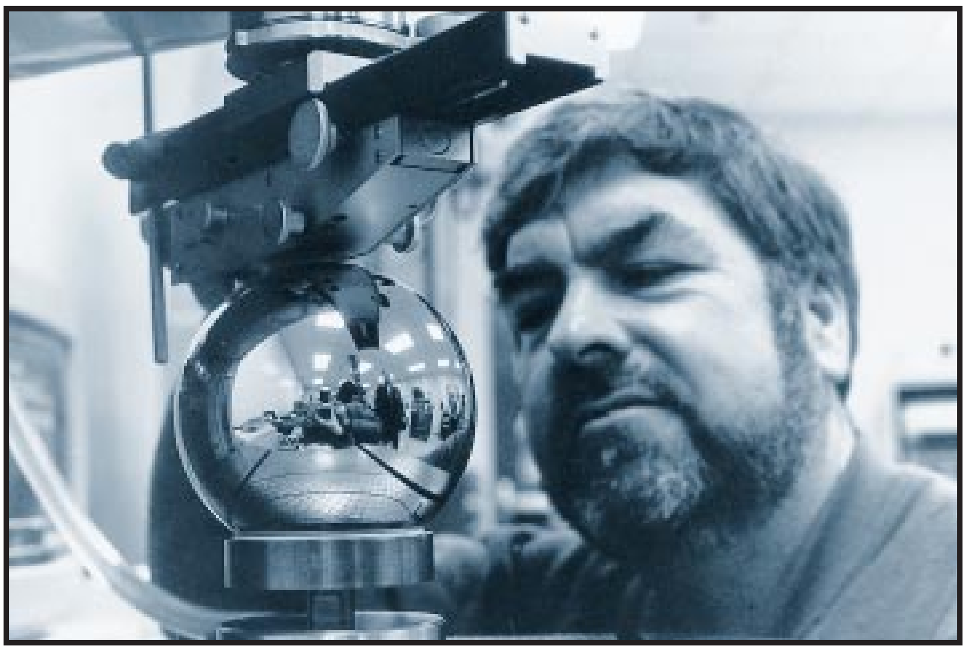
Reprocessing plants have generated 105 million gallons of highly radioactive and hazardous chemical waste–enough to fill a 1,000-foot-long supertanker. High-level reprocessing wastes contain almost 99 percent of the total radioactivity left from nuclear weapons production. They also contain long-lived radioactive elements that could pose environmental risks for tens of thousands of years. Reprocessing also generated billions of gallons of wastewater. Although this wastewater contained only about 1 percent of the radioactivity and trace amounts of chemicals, it caused widespread contamination because it was discharged directly to the ground during the Cold War.

A glovebox for handling plutonium is a sealed environment kept under negative pressure and, when necessary, filled with inert gas to keep the plutonium inside it from igniting in air. Safety procedures require this plutonium worker to wear anticontamination clothing and to handle plutonium through rubber gloves attached to the wall of the box. *Plutonium Finishing Plant, Hanford Site, Washington. December 17, 1993.*

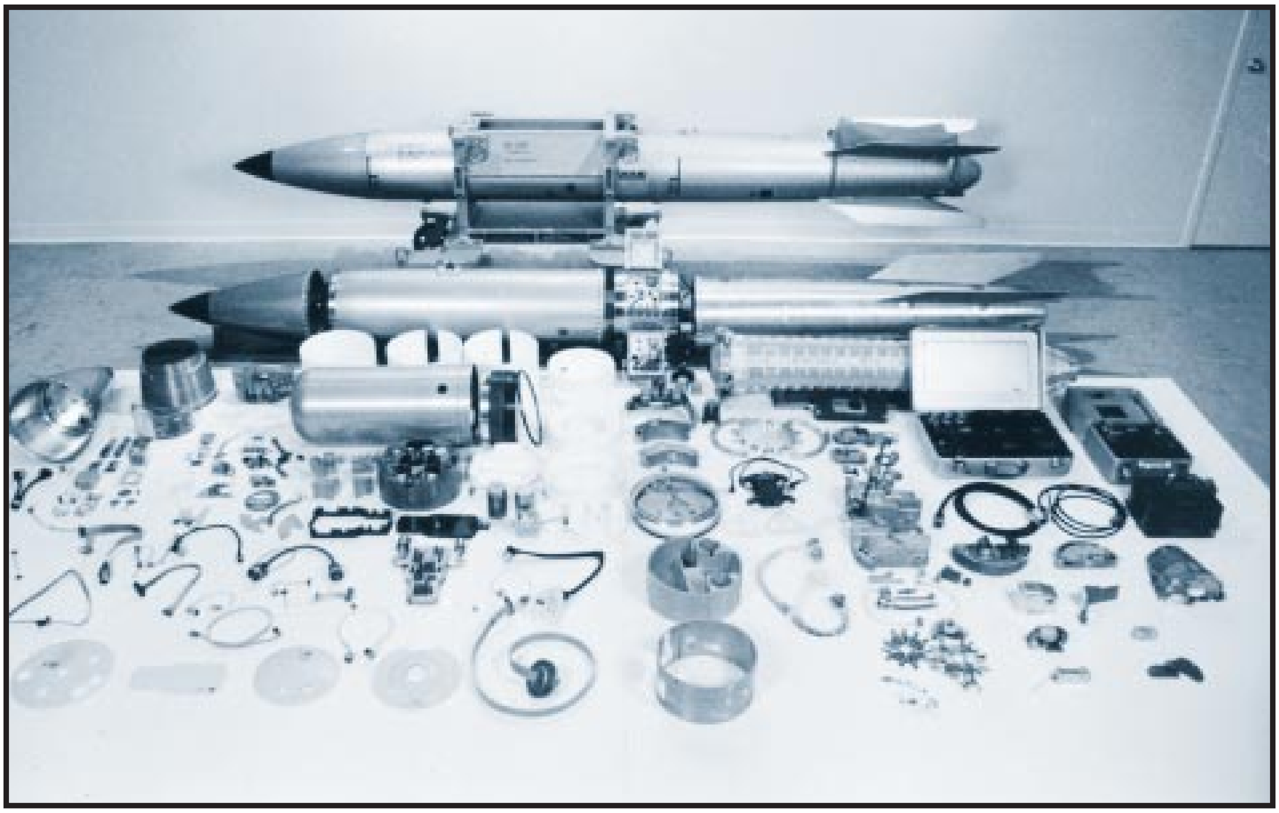
Plutonium Metallurgy

Most plutonium from the reprocessing plants went to the Rocky Flats Plant in Colorado to be machined into warhead components. It was usually in the form of a metal, but liquid and powdered forms of plutonium were also produced. The weapons laboratories used some plutonium to make and test prototype designs for weapons.

Plutonium can be extremely dangerous, even in tiny quantities, if it is inhaled. Because of these hazards, plutonium metallurgy required workers to use gloveboxes equipped with safety and ventilation systems.



Calibration spheres like this one surveyed by Y-12 machinist Danny Bush were used to set instruments that check the manufacturing specifications for weapons parts. Crucial components of nuclear warheads must be accurately shaped to within a few millionths of an inch. *Y-12 Metrology Laboratory, User Facility Skills Demonstration Center, Y-12 Plant, Oak Ridge, Tennessee. January 12, 1994.*



An example of a completed nuclear weapon and its component parts. At top, an intact B-61 nuclear bomb. At bottom, the assemblies and subassemblies that comprise this weapon. Dozens of facilities across the country engage in different processes and contribute specific parts to the production of nuclear weapons.

Weapons Design

Research, development, and testing have been a critical part of the nuclear weapons enterprise. Two national laboratories – at Livermore, California, and Los Alamos, New Mexico – devoted their expertise to this work during the Cold War. A third laboratory – Sandia National Laboratories, based in Albuquerque, New Mexico – worked on the electronic mechanisms for nuclear warheads as well as designs for coupling the warheads to bombs and missiles. Many different types of nuclear bombs and warheads have been manufactured in the United States, and some additional designs were partially developed.

Final Assembly

Factories in several States (Florida, Missouri, Ohio) contributed components for the final assembly of nuclear weapons. Final assembly occurred primarily near Amarillo, Texas, at the Pantex Plant. The assembly process did not create much radioactive waste.

With the end of the Cold War, the Department of Energy has reversed the activities at Pantex. The plant now disassembles warheads that have been retired from the nation's arsenal, and it is now storing most of their plutonium components. Uranium components are shipped to Oak Ridge, Tennessee. Tritium canisters are shipped to the Savannah River Site in South Carolina. Interim storage and ultimate disposition of surplus nuclear weapons materials pose a number of challenges, such as worker and public safety and security against potential theft.

“Gravel gerties” are concrete structures whose roofs consist of cable mesh supporting large amounts of gravel. Beneath them are bays, where workers assemble and disassemble nuclear warheads. Should a warhead’s conventional explosives accidentally detonate, the roofs of these structures are engineered to give way, releasing the gravel and trapping the plutonium particles. Up to 2,000 warheads per year are now being dismantled at this site. *Pantex Plant, Amarillo, Texas. November 18, 1993.*

Testing

During the past 50 years, the United States exploded more than 1,000 individual nuclear devices in atmospheric, underwater, and underground tests. Most of the nuclear weapons tests were conducted in Nevada, but tests were also done in the Pacific Ocean, Alaska, the south Atlantic, and New Mexico. Nuclear explosion tests were also conducted in Colorado, New Mexico, Mississippi, and Alaska for non-weapons purposes. These tests were done to explore the potential use of nuclear explosions to extract natural gas or to dig harbors. Radioactive contamination from testing remains at most of the test sites.

The United States stopped atmospheric testing in 1963 and has not conducted any nuclear explosion tests since September, 1992.

The Pantex Plant, near Amarillo, Texas, now disassembles nuclear warheads and is storing their plutonium components.